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IDENTIFICATIONS OF *Einstein* SLEW SURVEY SOURCES

JONATHAN F. SCHACHTER, MARTIN ELVIS, DAVID PLUMMER,
AND G. FABBIANO
Harvard–Smithsonian Center for Astrophysics
60 Garden St. Cambridge MA 02138 USA

ABSTRACT

We discuss the status of identifications of the *Einstein* Slew Survey, a bright soft X-ray catalog with 550 new X-ray sources. Possible counterparts have been found for > 95% of the Slew Survey based on positional coincidences and color-color diagnostics. The survey will be fully identified via upcoming radio and optical observations.

1. Introduction

The *Einstein* Slew Survey is an all-sky survey covering 50% of sky at an exposure of 6 s. It contains 1067 bright soft X-ray sources ($\gtrsim 5 \times 10^{-12}$ erg cm^{-2} s^{-1}, 0.1 – 3.0 keV) with a positional accuracy of 1.2′ (90% confidence radius), of which 550 were not previously known to emit X-rays. A paper which includes the details of source detection, derivation of positions and fluxes, and an extensive catalog of all 1067 sources has been submitted for publication (Elvis et al. 1991). All the photon data, useful lists, and software tools are available either on CD–ROM (from the *Einstein* Data Products Office at CfA; email: edpo@cfa.harvard.edu) or via *einline*.

2. Identified Sources

2.1 *Counterparts of Known Optical Type*

We have found possible counterparts for 96% (1021 sources) of the Slew Survey based on positional coincidences found in an extensive search of existing catalogs and databases. For 650 sources, the counterpart is a known optical type, including all known types of X-ray sources—AGN, BL Lacs, clusters, CVs, X-ray binaries, supernova remnants, pulsars, stellar coronal sources, and white dwarfs (Table 1).

2.2 *Counterparts of Unknown Optical Type*

Of the fraction lacking counterparts of known optical type, 363 have possible counterparts in the Hubble Guide Star Catalog (GSC). This reflects the GSC completeness ($B \sim 14.5$), and is consistent with the expected distribution of V magnitudes of unidentified sources, based on known X-ray-to-optical flux ratios (Stocke et al. 1991). There are 79 sources with only one GSC candidate in the Slew Survey error circle. We have tentatively identified new late-type stars ($V \sim 11 - 14$) and new AGN ($V \sim 14 - 16$) in this group. There are typically 3.7 GSC sources per Slew Survey source, with a range of 1 – 3 magnitudes. An unambiguous identification requires information from catalogs at other wave bands.

Of 15 new counterparts in the *IRAS* Point Source Catalog, the low-Galactic latitude subset contains 2 probable new T Tauri stars (in Cassiopeia) and one molecular cloud core (near W44). Positions of molecular clouds are from Dame et al. 1987, and *IRAS* color-color diagnostics from Emerson 1986. In the high-latitude sources, we find 4 AGN candidates, and two starburst galaxies. Extragalactic *IRAS* color diagnostics are taken from Soifer, Houck, & Neugebauer 1987. We also find 6 new counterparts in the *IRAS* Faint Source Catalog.

There are 22 new 5 GHz CBS (Condon, Broderick, & Seielestad 1989) identifications lacking optical counterparts, with $f_{5GHz} = 27 - 4660$ mJy. Two of these sources are flat spectrum sources, and may be new BL Lac objects. The remaining sources are probably AGN, BL Lacs, and clusters, as these dominate the optically identified Slew Survey sources with CBS counterparts.

We find 45 sources lacking counterparts in any of the catalogs searched. These have the most extreme X-ray–to–optical fluxes of any Slew Survey sources, and are probably mainly BL Lacs and clusters. Radio spectral indices from the upcoming Becker et al. (1991) 1400 MHz and southern radio surveys will aid in identification. We are planning to obtain VLA and optical spectroscopy on these sources (starting in June, 1991) to progress the survey to 100% identification.

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Table 1: Identified Sources of Known Optical Type

Class	Num. New X-ray Src.	Total Num. IDs.
AGN	9	128
BL Lacs	0	32
Clusters	9	80
CVs	0	22
Stars	81	231
X-ray binaries and Pulsars	0	41
Other:	6	93
Norm. Galaxies	5	16
SN Remnant	0	27
White Dwarf	1	6
2E Sources	0	41
EXOSAT Sources	0	2

THE *Einstein* SLEW SURVEY CATALOG

JONATHAN F. SCHACHTER, MARTIN ELVIS, DAVID PLUMMER,
G. FABBIANO, and JOHN HUCHRA
Harvard–Smithsonian Center for Astrophysics
60 Garden St. Cambridge MA 02138 USA

Abstract

The Slew Survey catalog contains 1075 bright X-ray sources, including 557 objects with no previous X-ray detection. Two-thirds of the survey has been identified with counterparts of known optical type. Source samples to date provide insight on low-luminosity AGN and clusters. The remainder, which contains many uncatalogued BL Lacs and clusters, will be identified by using digitized photographic plates.

1 INTRODUCTION

All-sky surveys can help to address key problems in X-ray astronomy. Among these problems are (1) low-luminosity active galactic nuclei (LLAGN) and the soft X-ray background, and (2) the cluster X-ray luminosity function. We briefly summarize each of these problems below.

1.1 LLAGN and the Soft X-ray Background

The steep luminosity function of AGN (meaning emission-line objects only) means that low luminosity AGN (e.g. Seyfert nuclei) are likely to provide a major part of the AGN contribution to the diffuse X-ray background (Schmidt and Green 1986). Yet optical color-selected samples (e.g. the Palomar Bright Quasar Survey; Schmidt and Green 1983) are incomplete at low luminosities ($M_V \geq -23$) because of dilution by host galaxy starlight. New X-ray–selected samples can be far more complete down to significantly lower luminosities ($M_V \sim -18$).

1.2 The Cluster Luminosity Function

Edge *et al.* (1990) constructed a flux-limited sample [$f_x(2 - 10$ keV $) > 1.7 \times 10^{11}$ ergs cm^{-2} s^{-1}] of 55 clusters selected from the *HEAO-1* and *Ariel V* surveys. They found a statistically significant deficit of high-luminosity ($L_x \geq 5 \times 10^{44}$ ergs cm^{-2} s^{-1}) clusters at $z > 0.1$. If this effect is real, and not the result of a selection bias or their choice of a flux limit, then evolution must have occurred in $z > 0.1$ clusters. (But the Slew Survey clusters appear to be both high redshift and *over*luminous; see below).

1.3 The *ROSAT* All-sky Survey

Ultimately, the *ROSAT* all-sky survey will provide a wealth of information to bear on these important problems. But the *ROSAT* survey, which will contain up to 100,000 sources, cannot plausibly be ready before the end of 1991. Even then, the identification effort required for the *ROSAT* medium and deep surveys is immense. To identify $\sim$ 800 sources with $18 < V < 22$ will take, optimistically, 50 clear dark-time nights on 4-meter class telescopes, i.e. almost 100% of a 4-meter's dark time for one year. The current MPE plan (Trümper 1991) is to identify ~2000 'medium survey' sources in a selected ~600 square degrees of the sky during the first three years (i.e. up to the end of 1993-94). This is only a factor ~2 more than the existing Extended *Einstein* Medium Survey (Gioia *et al.* 1990).

For a decade now X-ray *logN-logS* studies have been dominated by results from the *Einstein* IPC. The *Einstein* Deep and Medium surveys have effective *upper* limits to their flux range due to their limited sky coverage. As a result we have only limited knowledge of the bright X-ray sky at low (IPC) energies. The energy range of *ROSAT* is significantly lower than that of *Einstein* so that obscuration, both Galactic and intrinsic, is even more significant; thus, the population of sources *ROSAT* will detect will be biased toward softer spectra. These difficulties will enlarge the ambiguities in explaining the diffuse x-ray background since its spectrum is only well determined at energies significantly above the *ROSAT* energy range.

2 THE EINSTEIN SLEW SURVEY

We have constructed an all-sky soft X-ray survey from ~3000 individual slewing (i.e. traveling between pointings) observations of the IPC (Elvis *et al.* 1991). The Slew Survey covers 50% of sky at 6 s exposure, and has a total effective exposure of $\sim 1/2 \times 10^6$ s (e.g., Fig. 1 of Plummer *et al.* 1991). Compared to the Medium Survey, the Slew Survey has a flux limit ~ 10 times higher (3×10^{-12} erg s^{-1}cm^{-2}, 0.2–4.0 keV) and has 30 times the area.

All the photon data of the Slew Survey, useful lists, and software tools are available either on CD-ROM (from the *Einstein* Data Products Office at CfA; email: edpo@cfa.harvard.edu) or via *einline*. A paper with updated counterpart identifications, and containing multiwavelength data for the Slew Survey (radio, IR, optical, soft and hard X-ray) is in preparation (Schachter *et al.* 1991).

Sources were detected by a percolation algorithm, which is more efficient than a sliding box method for a spatially sparse data set. We accepted sources as real if the Poisson probability of the observed counts relative to the local background is greater than 3.95×10^{-4} and the total number of counts in the source is ≥ 3. This yields a catalog of 1075 objects, the largest bright X-ray catalog to date, including 557 new X-ray sources.

A positional accuracy of 1.2′ (90% confidence; 3′ at 95% confidence) was achieved. The principal limitati ɔn on source localization is the slew aspect solution (details in Elvis *et al.* 1991).

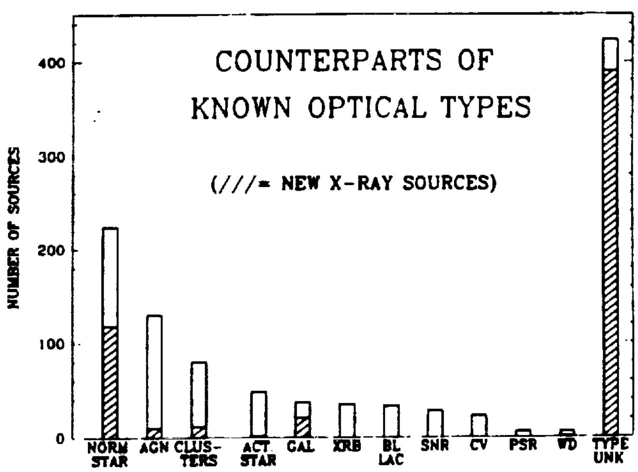

Figure 1: Bar chart showing breakdown of Slew Survey sources possessing counterparts of known optical types. For each type, the hatched region represents the proportion of new X-ray sources. Abbreviations used are *NORM.* and *ACT.* for normal and active.

3 COUNTERPARTS OF SLEW SURVEY SOURCES

3.1 Sources with Known Optical Types

We have performed an exhaustive search of standard catalogs of stars, galaxies, AGN and BL Lacs, clusters of galaxies, cataclysmic variables and X-ray binaries (see §6 of Elvis *et al.* 1991). In addition, we have searched the Simbad and NED databases. This program yields counterparts of known optical type (e.g., AGN, CV) for 2/3 of the survey. A bar graph (Figure 1) shows the relative numbers of sources with known optical types; also indicated are the fractions of each type that are new X-ray detections. Clearly, we have objects of every known type of X-ray source. Examples of new samples of sources are discussed below.

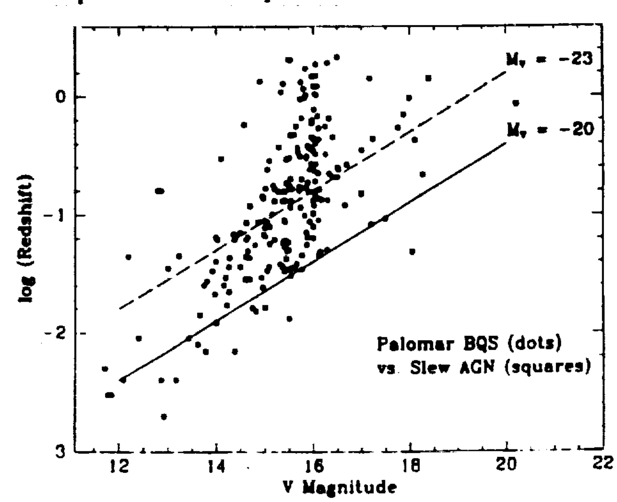

Figure 2: Redshift–V magnitude distribution for the Palomar Bright Quasar Survey (BQS; solid dots), and for identfied Slew Survey AGN to date (squares). The broader distribution in V magnitude for the Slew Survey AGN is a consequence of the X-ray selection. The Slew Survey AGN are seen to be intrinsically 3 magnitudes fainter in M_V.

Table 1: New Identified X-ray Clusters

Name	Slew Name	R	D	z	IPC Ct. Rate	log L_X
A193	1ES0122+084B	1	4	0.048	$0.21^{+0.07}_{-0.06}$	$45.81^{+0.13}_{-0.14}$
A773	1ES0914+519	0	6	~0.20	$0.22^{+0.10}_{-0.08}$	~47.06
A1602	1ES1241+275	0	6	~0.24	$0.32^{+0.15}_{-0.12}$	~45.39
A1651	1ES1256−039	1	4	0.083	$0.51^{+0.20}_{-0.17}$	$44.67^{+0.14}_{-0.17}$
A1664	1ES1301−239	2	6	...	$0.20^{+0.07}_{-0.06}$	...
A2495	1ES2247+106	0	5	...	$0.76^{+0.33}_{-0.26}$	...
A3404	1ES0644−541	1	5	...	$0.27^{+0.09}_{-0.08}$	...
A3866	1ES2217−354	0	5	...	$0.40^{+0.21}_{-0.16}$	...
S724	1ES1310−327	0	4	...	$1.78^{+0.42}_{-0.36}$	...
S1158	1ES2349−561	0	5	...	$0.88^{+0.43}_{-0.33}$	...
ZW 314	1ES0058+345	...	...	...	$1.14^{+0.71}_{-0.51}$	...

3.1.1 Identified Slew Survey AGN to date

There are 130 Slew Survey sources with counterparts in catalogs of AGN, of which 10 are new X-ray sources. One of the new X-ray sources is S5 0836+710, which has $z = 2.2$. To the list of identified AGN, we will probably add many of the new X-ray galaxies (21 to date) found in galaxy catalogs, but not currently known to possess active nuclei.

The identified Slew Survey AGN to date are compared with the Palomar Bright Quasar Survey sample in Figure 2. Clearly, the Slew Survey sample can detect sources at least 3 magnitudes fainter in M_V, showing the efficiency of detecting LLAGN. Plotting the Slew Survey and the Medium Survey AGN on a similar graph (not shown) shows that the two samples can be readily combined to sample a large range of luminosity-redshift space.

3.1.2 Identified Clusters

We find 80 cluster counterparts, of which 11 are new X-ray detections. The new X-ray clusters are listed in Table 1, with richness class (R), distance class (D), and redshift for each. IPC count rates have been converted to X-ray luminosities for the sources with known or estimated (Huchra *et al.* 1991) redshifts, using $H_0 = 50$ km s^{-1} Mpc^{-1}. Note that the clusters are all high z (or large D), i.e. $z \gtrsim 0.1$, and also high L_X. This would tend to go against the Edge *et al.* (1990) result (§1).

3.1.3 Identified Active Stars

Some 48 stars in the Slew Survey were previously known to be active (e.g., FK Com, RS CVn, AD Leo). Of the stars *not* known to be active, but identified in normal stellar catalogs, there are 151 late-type (> F) counterparts, including 91 new X-ray sources. The spectral types of these new X-ray sources often suggest coronal activity (e.g., FIII). Many cases (> 30) have been confirmed in ongoing observations by R. Remillard of MIT at the MDM 1.3 m, and S. Saar of CfA with the echelle spectrograph at the McMath 1.6 m.

3.2 Counterparts without Known Optical Types

3.2.1 Predicted Optical Properties

There are 502 Slew Survey sources without known optical magnitudes, of which 79 have known optical types (mainly supernova remnants and low Galactic-latitude X-ray binaries), and the remaining 423 lack counterparts of known type. For this last group, we can estimate the distribution of V-magnitudes. This distribution is a useful diagnostic of the amount of optical observing required for complete identification. We use values of the X-ray-to-optical flux ratio (f_X/f_o) from Stocke *et al.* (1991), and the relation 1.0 IPC cts s^{-1} = 3.26×10^{-11} erg cm^{-2} s^{-1} (0.2–4.0 keV), appropriate to a power-law energy index of 0.5 and $N_H = 2.0 \times 10^{20}$ cm^{-2} (Gioia *et al.* 1984).

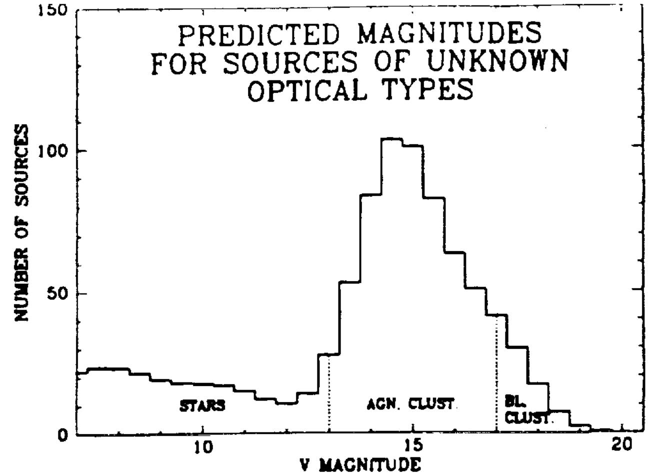

Figure 3: Histogram of predicted V magnitudes for the 423 sources in the Slew Survey currently lacking optical types. The distribution has been divided into three regions, containing bright, relatively bright, and faint objects. The main and secondary contributors to each of these three regions are listed.

The estimated V-magnitude histogram is given in Figure 3, where the typical uncertainty in determination of V is 1 mag. The bright end of the distribution ($V \leq 13$) is dominated by stars, where the lower limit depends on the completeness of stellar catalogs already searched. AGN account for the prominent $\sim$2 mag wide feature centered at $V = 15$, while clusters and BL Lacs dominate the faint end (to $V = 19-20$). There are some 24 objects expected to be fainter than $V = 18$.

We see that all the sources are expected to have readily detectable counterparts in either the Palomar Optical Sky Survey or the UK Schmidt plates. A sizable fraction (66%) are far enough from the Galactic plane ($|b| \geq 20°$) so that confusion is not a severe problem. The large number of unidentified sources and the large error radius suggest that we need other discriminants for a true counterpart determination.

3.2.2 Radio and IR Counterparts

We have searched the Becker, White & Edwards (1991) catalog compilation of the the Green Bank 5 GHz survey of the northern sky [$0° \leq |b| \leq 75°$; Condon, Broderick, & Seilestad 1989 (CBS)] to find counterparts to Slew Survey sources. Radio spectral indices (5 GHz – 0.365 Mhz) have also been tabulated by Becker *et al.* Figure 4 is an example of a diagnostic diagram to identify CBS counterparts. We show all the Slew Survey CBS counterparts known to be clusters, AGN, or BL Lacs; we also show the three CBS sources lacking optical counterparts (A, B, and C). On the basis of Figure 4, sources B and C are probably BL Lacs.

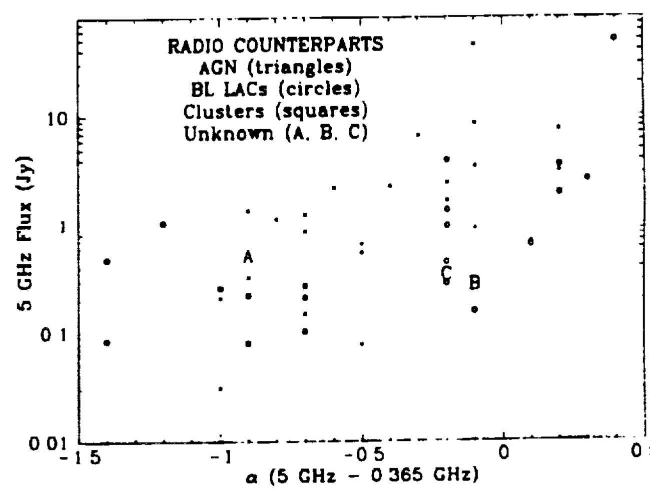

Figure 4: Technique for determining optical types for Slew Survey sources with radio counterparts. Known AGN, BL Lacs, and clusters of galaxies in the Slew Survey are indicated with triangles, circles, and squares. The letters A, B, and C indicate counterparts of unknown optical type.

We will obtain 1400 Mhz fluxes for all the northern objects using the sky maps of Condon and Broderick (1985, 1986). Existing southern sky surveys (PKSCAT90; Condon *et al.* 1991) are not nearly as deep as the CBS survey. Therefore, we plan to use the PMN survey, which is the southern complement of the CBS survey (at 5 GHz and 843 MHz; described elsewhere in these proceedings).

IRAS Point Source Catalog colors suggest two new candidate T Tauri stars, one new molecular cloud core, BL Lacs, AGN, and starburst galaxies (color-color diagnostics from Emerson 1986 and Soifer, Houck, & Neugebauer 1987).

3.2.3 Hubble Guide Star Catalog Counterparts

For the 502 Slew Survey sources lacking optical magnitudes, we find 364 possible identification in the Hubble Guide Star Catalog (GSC). This is consistent with the predicted magnitude distribution of the Slew Survey (Figure 3) and the GSC flux limit of $V \sim 16$. There are an average of 3.7 possible counterparts per Slew

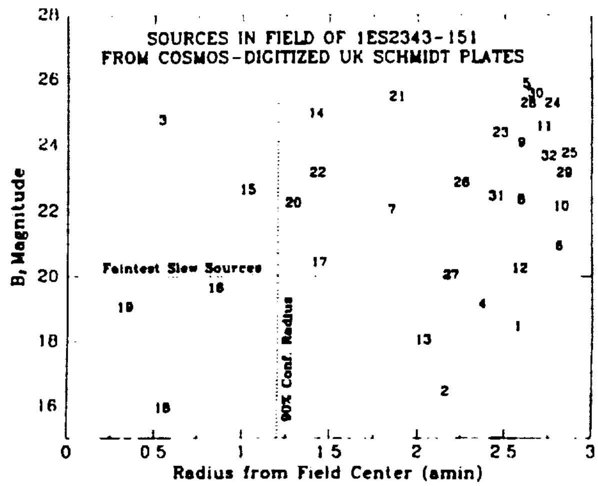

Figure 5: Magnitude distribution of sources in the field of the Slew Survey source 1ES2343−151 as a function of central radius. All sources detected in the digitized UK Schmidt plate are listed by number. The most likely Slew Survey counterparts lie in the box at the lower left.

Survey source, although one of these is probably just a chance superposition. The GSC has typically 100 sources per square degree (Lasker, these proceedings).

4 DIGITIZED RESOURCES

4.1 Overview

Using the results of the previous section, we find 45 sources (or only 4% of the survey) lacking any sort of counterpart. That is, these Slew Survey sources are (1) absent from standard catalogs, (2) absent from IRAS and radio surveys, and (3) absent from the GSC. These sources are expected to have the most extreme values of f_x/f_o and hence are mainly uncatalogued BL Lacs and clusters.

This again shows the advantage of X-ray selection. For example, the BL Lacs will be part of the ~100 total BL Lac objects in the Slew Survey. This can be compared with only 87 in the *entire* Hewitt & Burbidge (1986) catalog. The BL Lac sample of the Slew Survey will be uniform and X-ray selected, which is the most efficient way to detect these sources (Stocke *et al.* 1989).

4.2 Digitized Searches

We have used the COSMOS-digitized UK Schmidt plates, via the database at the Naval Research Laboratory (NRL). This work is in collaboration with H. Gursky and colleagues (principally B. Stuart, J. Wallin, and D. Yentis). Our initial interest was to obtain spectra of all objects in fields of sources favorable to the MMT ($\delta > -27°$). There are typically 25-50 objects within the conservative 3′ (95% confidence) radius down to the plate limit ($B_J \sim 23$). The brightest objects in our fields have $B_J \sim 16-17$, e.g. 1ES2343−151 (Fig. 5). We find typically 3 to 6 sources with $B_J \leq 19$. The faintest Slew Survey sources should lie near the upper limit.

In a recent run at the MMT Blue Channel (covering 3200-7000 Å) we observed three Slew Survey fields (1ES1355−086, 1ES2248−163, and 1ES2343−151). We suspect that object number 19 in the field of 1ES2343−151 is the optical counterpart, a faint galaxy with λ4686 absorption (Figure 6). This may be a member of a faint cluster.

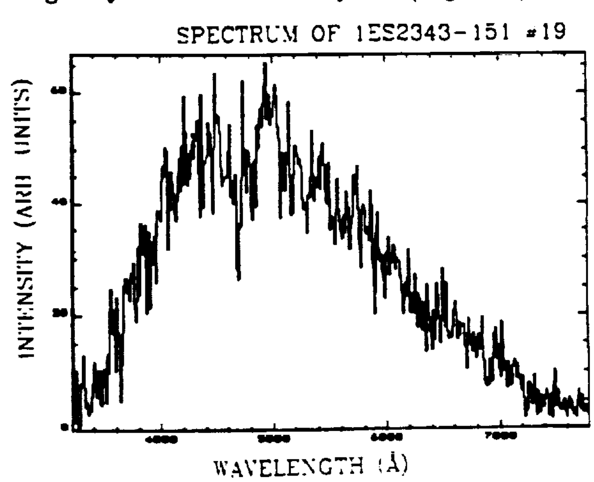

Figure 6: MMT Blue Channel spectrum of object no. 19 in the field of the Slew Survey source 1ES2343−151. He II λ4686 absorption is seen, suggesting that the counterpart is a member of a faint cluster.

In the near future, we will query the NRL database for all the southern sources. Our collaborators at the University of Minnesota are providing digitized magnitudes for the 4% of the Slew Survey with no counterparts from the the Palomar plates (Pennington, these proceedings). The usefulness of having two-color information for X-ray source identification is apparent.

We are committed to complete identification of the Slew Survey. We have ongoing observing programs to verify the new X-ray identifications, via optical spectroscopy at the Mt. Hopkins 60", the MMT, and southern telescopes, in addition to existing collaborations on the Kitt Peak telescopes described in an earlier section. Radio positions will be obtained with the aid of the VLA, which significantly reduces the number of possible counterparts in a given field. This can be used to pick out BL Lacs.

All of the Slew Survey sources are expected to be strongly detected (> 100 counts) in the *ROSAT* all-sky survey. In a collaboration with Dr. J. Trümper of MPE, we will search the *ROSAT* survey at the Slew Survey positions. Slew Survey sources constitute a *ROSAT* survey subsample of manageable size with some of its most interesting objects.

This research has made use of the Simbad database, operated at CDS, Strasbourg, France; and also the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA. Our work was supported by NASA grant NAG5-1201 (ADP).

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6 QUESTION AND ANSWER PORTION

L. Miller (ROE): Can you rule out the Edge *et al.* result? If so, do you have an explanation for what they see?

J. Schachter: Our new identified X-ray clusters are interesting, I think, because they are not what you would expect from the Edge *et al.* work. But we really need to have the all the Slew Survey clusters identified (all $\sim$200 rather than just 80) before we can make a detailed quantitative comparison with other samples.